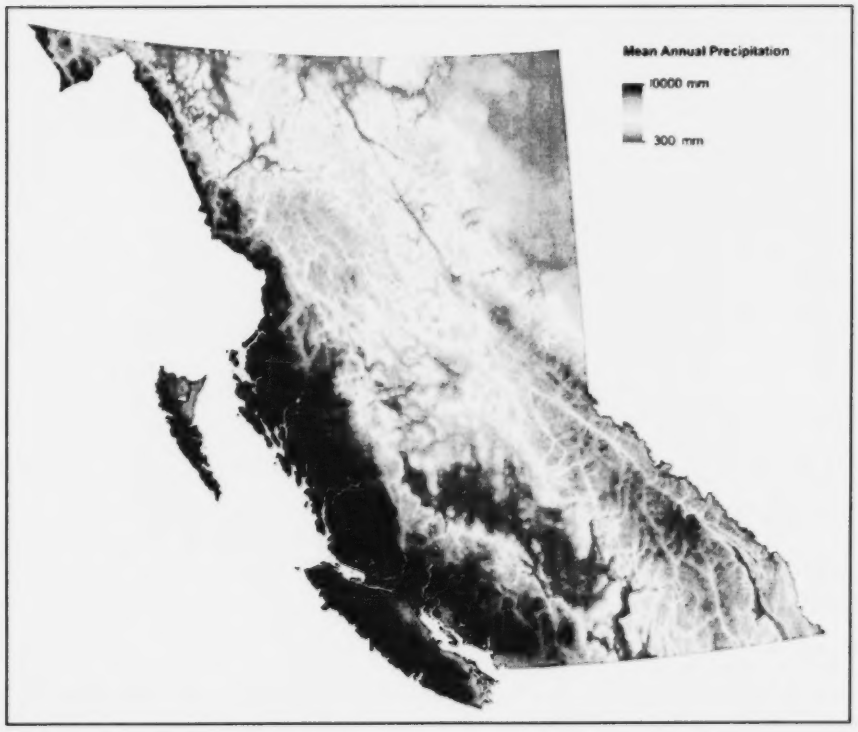
Final Report for Project Y062149

Spatial climate data and assessment of climate change impacts on forest ecosystems

Complied by David L. Spittlehouse

Project team

Dave Spittlehouse, Senior Research Climatologist, Research Branch, BC Ministry of Forests and Range, Victoria.
Marvin Eng, Landscape Ecologist, Research Branch, BC Ministry of Forests and Range, Victoria.
Andreas Hamann, Assistant Professor, University of Alberta, Edmonton.
Del Meidinger, Research Ecologist, Research Branch, BC Ministry of Forests and Range, Victoria.
Tong-Li Wang, Assistant Director, Centre for Gene Conservation, UBC, Vancouver.



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Abstract

Applying climate data in resource management requires matching the spatial scale of the climate and resource databases. In this project we developed a methodology to generate scale-free climate data through the combination of interpolation techniques and elevation adjustments. The method was applied to monthly temperature and precipitation normals for 1961-90 for British Columbia, Yukon Territories, the Alaska Panhandle, and parts of Alberta and United States produced with the Parameter-elevation Regressions on Independent Slopes Model (PRISM). Equations were developed to calculate biologically and hydrologically relevant climate variables (including degree-days, number of frost-free days, frost-free period and snowfall) from monthly temperature and precipitation data. Estimates of climate variables were validated using an independent data set from weather stations that were not included in the development of the model. Weather station records generally agreed well with estimated climate variables and showed significant improvements over original PRISM climate data. A stand-alone MS Windows® application (ClimateBC) was developed to perform all calculations and to integrate predictions of future climate from various global circulation models.

Examples of applications of the spatially distributed, scale-free data are presented. Data produced by ClimateBC was used to determine climatic moisture deficits on an elevation transect on Vancouver Island. Climate data at 400 m grid spacing were overlain on subzone variant maps of the Biogeoclimatic Ecosystem Classification system to provide descriptions of variant climates. This was repeated for future possible climates and assessments made of changes in climate of selected ecosystems and potential responses of the vegetation. The influence of climate change on snow accumulation and melt at a high-elevation forest site was evaluated. Data and programs are available through web sites.

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Introduction

Applying climate data in resource management requires matching the spatial scales of climate and resource databases. However, the network of weather measurements is sparse and usually measurements are not made anywhere near the location of interest. Consequently, the requisite information must be predicted by interpolation. Furthermore, there is the need to determine biologically relevant variables such as degree-days and frost-free period from the interpolated temperature and precipitation data.

Various methods have been developed for interpolating continuous surfaces (maps) of climate. These include aspect and elevation related correlations, multiple linear regression, flat plate splines and weighting functions to simulate climatological processes (Running *et al.* 1987, Refeldt *et al.* 1999, Price *et al.* 2000, Daly *et al.* 2002). British Columbia provides a major challenge for interpolating climate data because of the mountainous terrain, the sparse network of stations that tends to be located at lower elevations and large areas with no coverage. The Parameter-elevation Regressions on Independent Slopes Model (PRISM- Daly *et al.* 1994, 1997, 2002) uses expert knowledge on spatial patterns of climate and their relationship with geographic features to enhance statistical techniques for interpolating climate data. It was chosen by Meteorological Service of Canada to provide a set of monthly temperature and precipitation maps for western Canada (YT, BC, AB, SK, MB). Gridded monthly average, maximum and minimum air temperature and total precipitation generated by PRISM were produced at a resolution of 2.5 arcmin (a tile of about 4 × 4 km) for the reference period 1961–1990. These data are complemented by an equivalent set of data for the adjacent United States.

PRISM climate data are based on each tile's average elevation; consequently, there may be discrepancies of up to 1200 m in mountainous areas between the PRISM tile mean elevation and the elevation of specific locations within the tile. Elevation differences of this size can result in large differences between predicted and observed values, particular for temperature variables. An additional limitation of PRISM is that it does not output climate variables that are relevant in hydrological, ecological and genecological studies (Tuhkanen 1980).

Climate normals are the arithmetic mean of weather measurements from weather station records over three consecutive decades (WMO 1989). However, we need to be able to assess the influence of current climate variability and future climatic change on the resources. By the end of the 21st century, temperatures in BC could be 2–5°C above current values and there will be changes in precipitation regimes (Houghton *et al.* 2001). Canada's Standing Senate Committee on Agriculture and Forestry (2003) emphasized the vulnerability of Canada's natural resource industries to climate change and the need for the forestry community to be proactive in assessing potential impacts of climate change and developing strategies to adapting to them. Reducing vulnerability to climate change is an important part of sustainable resource management (Spittlehouse and Stewart 2003, Spittlehouse 2005). Consequently, we need to adapt the high resolution data to include future climate scenarios.

This report describes the process of increasing the spatial resolution (downscaling) of the PRISM data for British Columbia to produce an essentially scale-free set of climate data. We also developed methods to determine derived variables such as degree days and frost free period from the normals data. Methods for determining inter-annual variability are also evaluated. Scenarios from several Global Circulation Models (GCMs) were combined with the high-resolution reference period surfaces to predict future climate surfaces for BC. A stand-alone MS Windows® computer application (ClimateBC) was developed to perform the downscaling process, calculate derived climate variables, and add climate change predictions from a selection of GCMs for any

desired point location, defined by latitude, longitude and elevation in the study area. Examples of using the high spatial resolution data for current and future climate in hydrological, ecological and genecological studies are presented.

Development of the High Spatial Resolution Data

The Spatial Mapping Group of Oregon State University developed the PRISM data (http://www.ocs.oregonstate.edu/prism/) used in this study for the Canadian and BC provincial governments using the 1961-1990 weather station normals. Our project used data for the region between 47 and 62°N in latitude and between 113 and 141°W in longitude, which includes British Columbia, the Yukon, and parts of Alberta, continental USA, and Alaska, an area of about 130 million ha (Figure 1). The PRISM data consists of gridded (2.5 arcmin) estimates of monthly average, maximum and minimum air temperature and total precipitation, i.e., 4 variables × 12 months = 48 'base' variables, as well as average grid tile elevations. Hamann and Wang (2004) developed the approach to downscale the PRISM data and included climate change scenarios. Additional techniques were developed to generate seamless geographical surfaces at high resolution, effectively resulting in scale-free climate data and to produce derived variables, such as growing degree-days, frost-free-period and snowfall (Wang *et al.* 2006a). A brief description of the methodology and its evaluation is presented here. By scale-free we mean that predictions can be made for any point on the landscape. Limitations of the predictions are discussed later.

Figure 1. Coverage of the high spatial resolution data (From Spittlehouse 2006).

Development of PRISM-based scale-free climate data: Polynomial functions were developed for each monthly temperature variable based on geographic coordinates (latitude, longitude and elevation) and their combinations and transformations as independent variables using PRISM data (over 150,000 interpolated observations). The partial derivative of this function with respect to elevation is the rate of change in a temperature variable (environmental lapse rate) in response to a change in elevation for any given latitude, longitude and elevation. Bilinear interpolation is applied to the 4 km PRISM data to interpolate to the latitude and longitude of specific locations.

Elevation adjustment is then applied to the interpolated monthly values. The amount of elevation adjustment for a given site is the partial differential equation multiplied by the difference between the site elevation and bilinear interpolated PRISM tile elevation. The relationships between monthly precipitation and geographic co-ordinates were not strong enough to give elevation adjustment functions for precipitation. Bilinear interpolation provided adequate adjustment for elevation.

Evaluation of PRISM-based scale-free data: The quality of all climate variable estimates was evaluated through the comparison between predicted and observed climate data for a set of independent weather stations. PRISM data were developed using weather station normals for the 1961-1990 period. The independent data set consists of records from 191 weather stations that had sufficient records to be included in the 1951-1980 normals but not in the 1961-1990 data set. Improvements of predictions using scale-free climate data relative to original PRISM data were evaluated by changes to the variance explained in observed climate data and by changes to the standard errors of predictions. Minor differences in temperature and precipitation between the 1961-1990 and the 1951-1980 data sets are not expected to cause biased evaluation because the differences should mostly affect the intercept of a linear relationship rather than the amount of variance explained and standard errors.

Inter-annual variability: The scale free data are for the 1961-90 normals. Thus, predictions can not be made for specific years, or other multi-year periods. Two approaches for assessing variability were evaluated. Monthly temperature and precipitation data for 11 weather stations across BC and one each in the Yukon and in Alberta were used in this component of the study. Standard deviations, coefficient of variation, skew and kurtosis were calculated for the 1961-90 period and for the whole of the station record.

Interpolated monthly climate-variability datasets have been constructed for the world by Mitchell and Jones (2005) for months in 1901-2002 relative to 1961-1990 monthly normals. Interpolation of variability data is expected to be more reliable than interpolating observed data. This is analogous to the data used to provide climate change scenarios discussed later. The BC component of Mitchell and Jones's data was converted to the format suitable for incorporation in the ClimateBC program.

Determination of derived variables: Derived climate variables (column 3 of Table 1) were estimated with linear or non-linear regressions (Appendix I). These were developed from observations of the variable and monthly temperature and precipitation at 493 weather stations throughout British Columbia, Yukon and parts of Alberta for the 1951-1980 period. It is not expected that these relationships would be dependent on the normals period.

Evaluation of derived variables: The scale-free PRISM data were used to generate monthly temperature and precipitation data for the locations of the 493 weather stations. These data were then applied to the equations to calculate the derived variables and these data compared with the "true" normals for the stations. Annual and seasonal precipitation and temperature variables (Table 1) were calculated directly from the scale-free monthly climate normals. This was repeated on 198 stations with greater than 19 years of record from the 1961-90 normals.

Additional variables: Work was started to determine how well other climate variables that are linked to temperature and/or precipitation can be obtained from the high spatial resolution data. Relative humidity, vapour pressure and vapour deficit may be possible. For example, in many environments the mean vapour pressure of the air is close to the saturated vapour pressure at the mean minimum air temperature. This variable can then be used in the calculation of the other humidity variables.

Table 1. Monthly, seasonal and annual temperature and precipitation data and derived variables available in the high spatial resolution data. Seasonal definitions are meteorologically based. Other periods can be calculated from the monthly data.

Monthly	Seasonal	Annual
January to December mean temperature (°C)	Winter mean temperature (°C) (Dec-Feb)	Mean annual temperature (°C) (MAT)
January to December mean maximum temperature (°C)	Spring mean temperature (°C) (Mar-May)	Mean temperature of the warmest month (°C) (MWMT)
January to December mean minimum temperature (°C)	Summer mean temperature (°C) (June-Aug)	Mean temperature of the coldest month (°C) (MCMT)
January to December precipitation (mm)	Autumn mean temperature (°C) (Sept-Nov)	Difference between MWMT and MCMT (°C) (DT)
	Winter mean maximum temperature (°C) (Dec-Feb)	Mean annual precipitation (mm) (MAP)
	Spring mean maximum temperature (°C) (Mar-May)	Mean May to September precipitation (mm) (MSP)
	Summer mean maximum temperature (°C) (June-Aug)	Annual heat: moisture index (AH:M) (MAT+10)/(MAP/1000)
	Autumn mean maximum temperature (°C) (Sept-Nov)	Summer (May to Sept) heat: moisture index (SH:M) (MWMT)/(MSP/1000)
	Winter mean minimum temperature (°C) (Dec-Feb)	Extreme min. temperature over 30 years (°C) (EMT)
	Spring mean minimum temperature (°C) (Mar-May)	Precipitation as snow (mm water equivalent) (PAS)
	Summer mean minimum temperature (°C) (June-Aug)	Degree-days below 0°C, (chilling degree-days) (DD < 0)
	Autumn mean minimum temperature (°C) (Sept-Nov)	Degree-days above 5°C, (growing degree-days) (DD > 5)
	Winter precipitation (mm) (Dec-Feb)	Day of the year on which DD > 5 reaches 100, date of budburst ($DD5_{100}$)
	Spring precipitation (mm) (Mar-May)	Degree-days below 18°C, (heating degree-days) (DD < 18)
	Summer precipitation (mm) (June-Aug)	Degree-days above 18°C, (cooling degree-days) (DD > 18)
	Autumn precipitation (mm) (Sept-Nov)	Number of frost-free days (NFFD)
		Frost-free period (days) (FFP)
		Day of the year on which FFP begins (bFFP)
		Day of the year on which FFP ends (eFFP)

Solar radiation is important for calculating plant photosynthesis and evaporation. In the 1951-80 and 1961-90 normals there are only 52 sunshine hour and four solar radiation stations in BC. Most are in valleys and do not represent conditions in the mountains. Solar radiation can be calculated from sunshine hours and the solar radiation above the atmosphere (Hay 1979). Bristow and Campbell (1984) and others have found that monthly sunshine hours can be estimated from the monthly temperature range (difference between the maximum and minimum temperatures) and solar radiation above the atmosphere. This part of the project investigated the variability in the coefficients of relationship between solar radiation and the temperature range for stations and whether there were patterns of variation around the province that could be used for interpolation.

Climatic moisture deficits or surpluses can be calculated if an evaporative demand can be determined. The climatic moisture deficit (CMD) is the sum of the monthly difference between a reference evaporation (E_{ref}) and precipitation. If E_{ref} is less than precipitation then the monthly CMD is zero (in this case the precipitation minus E_{ref} is a climatic moisture surplus). If the average monthly air temperature is less than or equal to zero then E_{ref} =0. An estimate of the monthly evaporative demand (E_{ref}) can be obtained from air temperature using the Thornthwaite method (Thornthwaite 1948, Mather and Abroziak 1986). Considering it's simplicity it is remarkable that it can give numbers within 25% of physically-based equations in a wide range of environments, though it fails badly in some extreme environments (and should be used with caution in climate change studies). The above-mention humidity and solar radiation variables would be of help in calculating a more realistic value of E_{ref}. They can be linked with plant response functions to allow calculation of site water balance (Allen *et al.* 1998, Spittlehouse 2003, 2004).

Evaluation of the High Spatial Resolution Data

Elevation adjustment: The polynomial functions developed using latitude, longitude and elevation to model monthly temperature based on PRISM data were all statistically significant ($P<0.0001$). PRISM predicted monthly maximum, minimum and average temperatures explained over 90% of the variance in most months (Figure 2) for the 191 test stations. Standard error of predictions for monthly temperatures and precipitation varied with each month (0.8–1.1°C for maximum temperature; 0.8–1.6°C for minimum temperature; 0.7–1.3°C for average temperature; 8–24 mm for precipitation). For all months and variables the R^2 was >0.9 and slopes of the regressions were approximately 1. We found a few weather stations that were not well predicted for certain variables. This result, possibly due to resolution of the PRISM data or to the ClimateBC interpolation procedure, indicates limits in the methodology. Examples for precipitation prediction are found in a few coastal stations.

The improvement of predictions by using scale-free climate data can be seen in maps of predicted mean annual temperature predicted for an area near Vancouver (Figure 3). Elevational adjustment of PRISM data (Figure 3A) improved the predictions (Figure 3B), but the boundaries among the original PRISM tiles are still visible. The reason for this is that differences among adjacent PRISM tiles are not entirely determined by elevation (Daly *et al.* 2002) and steps can occur at the boundaries between neighbouring tiles. The combination of bilinear interpolation and elevation adjustment overcame this problem and produced a smooth surface of predicted mean annual temperature that matches the topographic surface and the associated temperature gradients (Figure 3C).

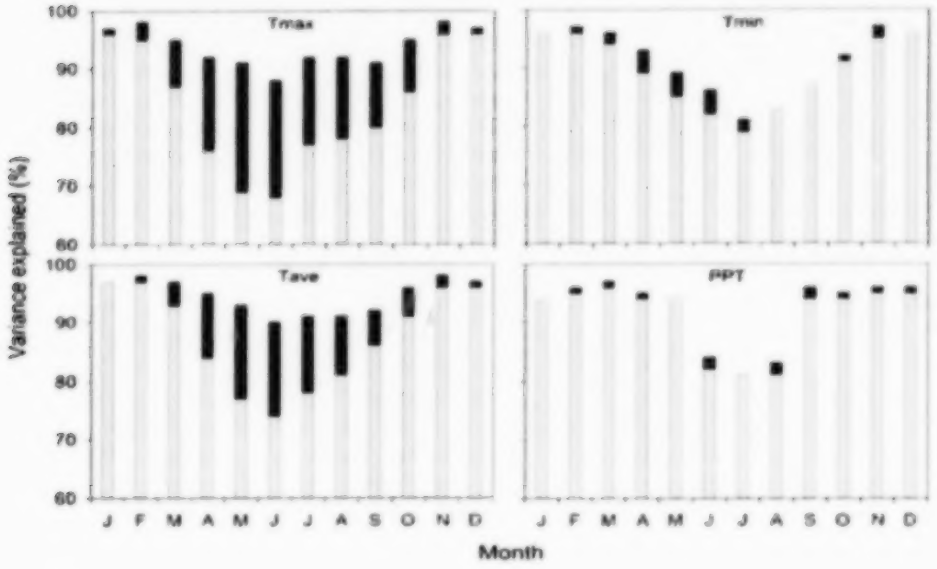


Figure 2. The amount of variance (%) explained in weather station data by predictions using original PRISM data (□) and PRISM based scale-free climate data (□ + ■) for monthly maximum (Tmax), minimum (Tmin) and average (Tave) temperatures, and monthly precipitation (PPT) (Adapted from Wang *et al.* 2006a).

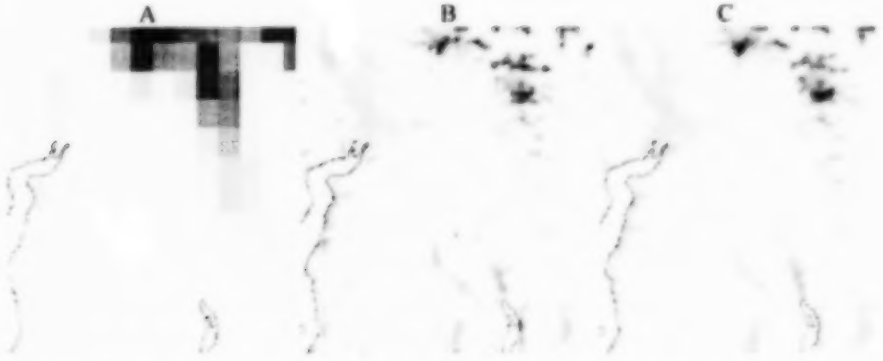


Figure 3. Maps of mean annual temperature predicted by PRISM data (A), elevation-adjusted PRISM data (B) and the combination of bilinear interpolation and elevational adjustment (C) for an area near Vancouver based on a high-resolution digital elevation model (100 x 100 m) (Adapted from Wang *et al.* 2006a).

Derived variables: Derived variable equations explained 90 to 95% of the variance in the original data (Figure 4). Applying these equations to PRISM based scale-free monthly data for the 493 weather stations resulted in relationships between estimated and observed values reduced R^2 values by about 0.07. Standard errors of the estimates were also increased. This is not a

surprise because downscaled PRISM monthly data involve errors. The standard errors were of 10–15% of a variable's value. The R^2 was >0.84 for all variables and >0.9 for degree-day variables and slopes of the regressions were close to 1 (Wang *et al.* 2006a).

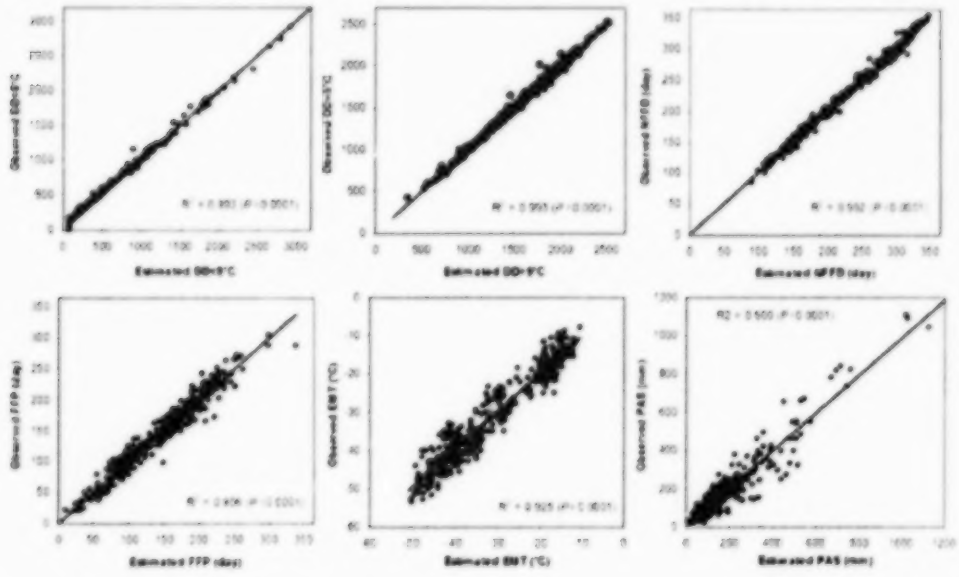


Figure 4. Relationships between observed and estimated climate variables, including degree-days < 0°C (DD<0°C), degree-days > 5°C (DD>5°C), Number of frost-free days (NFFD), Frost-free period (FFP), extreme minimum temperature (EMT) and precipitation as snow (PAS) (Adapted from Wang *et al.* 2006a).

Inter-annual variability: Inter-annual variability for temperature increased inland from the coast and from south to north. Maximum temperatures showed greater variability than minimum temperatures and variability was greater in the winter than in the summer. For example, at Victoria in coastal BC one standard deviation is 1.7°C on the mean maximum January temperature and 1.2 °C for July. The respective values for Dease Lake in the northern interior are 5.7 °C and 1.8 °C. Standard deviations for January and July mean minimum temperatures for Victoria are respectively 1.7 °C and 0.5°C, and for Dease Lake they are 6.0 °C and 1.0 °C. Seasonal averages show less variation. Values for the 1961-90 period were similar to those for the full length of the station record, up to 100 years for some stations.

The large range in mean precipitation in BC means that evaluation of variability is best done through the coefficient of variation. It does not show distinct spatial patterns or seasonal variation like temperature. As a percentage it varied from the low 40s to low 70s. Seasonal totals had a coefficient of variation from the mid 20s to the high 30s. The measure of skew of monthly precipitation varied from -0.3 to 1.4 for Victoria and 0.1 to 2.1 for Dease Lake. The measure of kurtosis varied from -1.3 to 3.5 for Victoria and from -1.1 to 1 for Dease Lake. The influence of inter-annual variation is illustrated in the hydrology section of the Applications chapter.

Version 3 of ClimateBC that incorporates the Mitchell and Jones data for BC is under evaluation. It is expected that the interpolations for annual monthly or decadal average monthly

temperature will have an accuracy similar to that for the normals. Annual monthly precipitation is likely to show lower accuracy.

Additional variables: This work is on-going. The ability to determine mean humidity variables is promising. We need to determine those environments where the air is not at 100% at the minimum air temperature. This is the case in some dry interior environments. The relationship between solar radiation and the temperature range was good for individual stations but did not show consistency between stations. There does appear to be some influence of distance from the coast on the coefficients, at least for summer conditions, and this will be investigated further. Examples of calculating E_{ref} and the climatic moisture deficit are presented later in the applications section.

Climate Change Scenarios

Global models make predictions of change in the temperature and precipitation normals for the 2020s, 2050s and 2080s (Canadian Climate Scenarios Network 2006). Predictions of changes to each of the base variables were generated for two global circulation models and three scenarios: CGCM1-gax, CGCM2-A2x and CGCM2-B2x of the Canadian Centre for Climate Modeling and Analysis (Flato *et al.* 2000) and HADCM2-gax, HADCM2-ggx and HADCM3-A2x of the Hadley Centre (Johns *et al.* 2003). The coverage was interpolated to a grid of 1° latitude by 1° longitude. The adjusted base variables are then used to calculate derived variables for the scenarios. Recent research using regional climate models to interpolate climate change scenarios to a 50 km resolution suggests that changes may not be uniform within a CGM grid box (Ouranos 2006).

ClimateBC – Access to Spatial Data

An interactive MS Windows® software application "ClimateBC", written in Visual Basic 6.0, performs all the calculations described above (Figure 5). The program outputs monthly, seasonal and annual climate variables for 1961-1990 normals, for the period 1998-2002 and for the 2020s, 2050s or 2080s based on latitude, longitude, and elevation (the latter is optional). It can process a single location through direct input of co-ordinates in decimal degrees or degrees, minutes and seconds by the user. Alternatively, multiple locations can be processed through reading an input file comprising co-ordinates listed in a spreadsheet or a text file. If elevation is not available, ClimateBC uses a mean elevation interpolated using binomial smoothing based on the 4km grid cell containing the location of interest and the surrounding cells. This elevation can be substantially different from the actual elevation.

Two versions of the program are available. One works on standard computer Microsoft XP® operating systems. The second is written for the modified version of XP® that is on most BC government computers that is missing the file comctl32.ocx. The programs, PRISM data and climate change scenarios are available from the Centre for Forest Gene Conservation at the University of British Columbia: http://genetics.forestry.ubc.ca/cfgc/climate-models.html.

A web-based version of the program is also available at the above-mentioned site. Latitude, longitude, and elevation are input and the site calculates the annual, seasonal and monthly variables for current of for future climate. This program will only process one location at a time.

ClimateBC was used to generate grid based data of the monthly temperature and precipitation at 400 m spacing using a digital terrain model at this resolution as the input. These

data are available at: ftp://ftp.for.gov.bc.ca/HRE/external/!publish/Climate/. Equations for calculating the derived variables (Appendix I) are available as is the methodology for incorporating climate change scenarios.

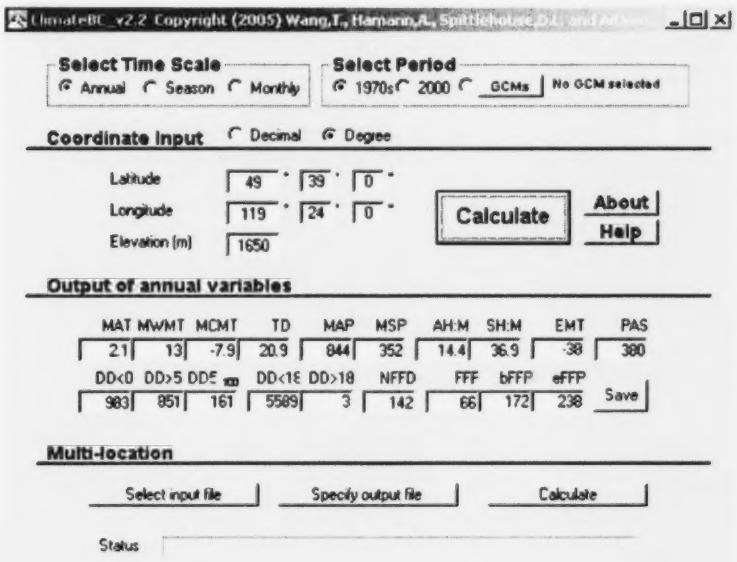


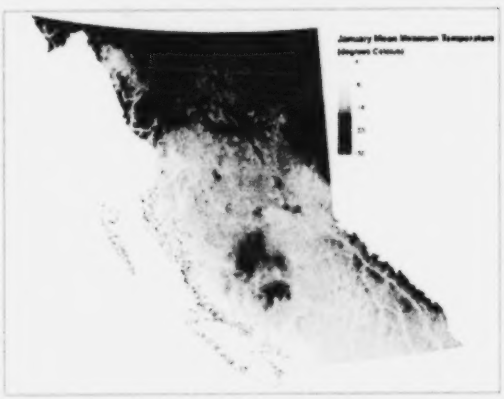
Figure 5. ClimateBC control screen. See Table 1 for the explanation of abbreviations for annual variables (from Spittlehouse 2006).

Applications of ClimateBC – Current Climate

Climate maps: Climate BC and provides spatial data to produce maps through batch mode and a file of latitude, longitude and elevation data from a digital terrain model (DTM). A DTM with 400-m grids was used in producing the climate data for the maps on the cover page and in Figures 6 and 7. A DTM at 100 m spatial resolution was used in producing panel C in figure 3.

Hydrology: ClimateBC can be used to estimate precipitation regimes of ungauged areas. For example, there are no long-term weather stations and only a few snow survey sites above 500 m on Vancouver Island. Figure 7 shows that mean winter precipitation can be over 5000 mm at high elevation. Overlaying watershed boundaries on high resolution precipitation data can produce an estimate of the volume of precipitation falling in such basins.

Data from ClimateBC can be used in determining climatological moisture deficits (CMD) and their inter-annual variation. For example, Spittlehouse (2003, 2004) created a long-term weather record for the Campbell River airport on Vancouver Island to be used for water balance calculations for forested sites. ClimateBC was used to determine the mean monthly temperature difference and the precipitation difference between the airport (100 m) and 600, 1100 and 1800 m elevations. This represents a transect from Douglas-fir forest, through western hemlock/cedar forest, mountain hemlock forest to alpine.



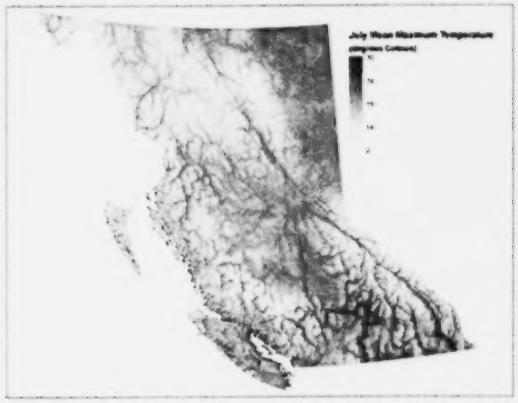
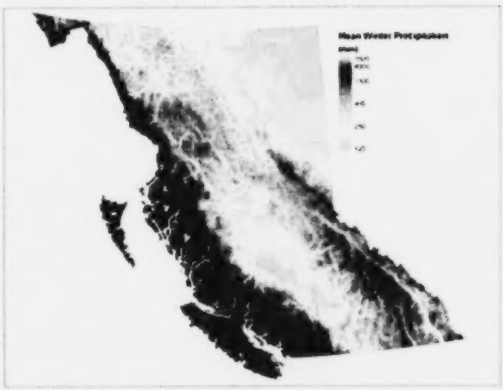


Figure 6. January mean minimum temperature (°C) and July mean maximum temperature (°C) for 1961-90 produced with ClimateBC at a 400 m resolution.



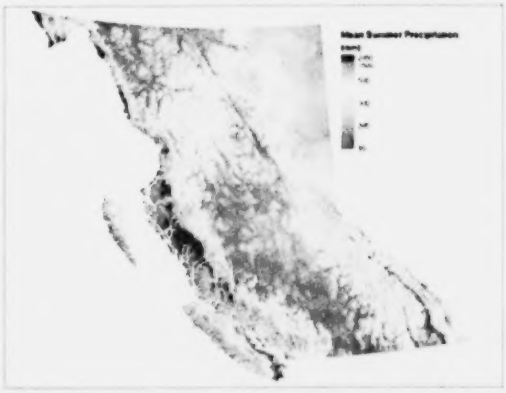


Figure 7. Mean winter (October to April) precipitation (mm) and mean summer (May to September) precipitation (mm) for 1961-90 produced with ClimateBC at a 400 m resolution.

Calculation of the monthly evaporative demand (E_{ref}) and CMD were done for the 1961-90 normals. Using normals underestimates the CMD compared to the mean of the CMD calculated for each year then averaged. For example, at Campbell River airport it was 201 mm from the normals versus the 230 mm average of the annual values. The method of Allen *et al.* (1998) based on solar radiation and humidity as well as temperature gave 240 mm. This indicates that using the normals in the Thornthwaite equation is adequate for comparisons between sites. The evaporative demand and the CMD decrease with elevation (Table 2). This is a function of the decrease in temperature and increase in precipitation. The CMD is restricted to the May through September period at 100 m, June to August at 600 and 1100 mm, and July and August at 1800m.

Table 2. Evaporative demand (E_{ref}), climatic moisture deficit (CMD), mean annual temperature (MAT) and precipitation (MAP) at four elevations on the east coast of Vancouver Island near Campbell River. E_{ref} for 1800 m is restricted to the June to September because snow would be covering the vegetation outside of this period. Evaporation is assumed to occur in forests when the air temperature is above zero even though there is snow on the ground below the canopy.

Elevation (m)	100	600	1100	1800
E_{ref} (mm)	605	555	496	340
CMD (mm)	201	135	94	55
MAT (°C)	8.4	6.9	5.1	2.0
MAP (mm)	1450	1860	2180	2590

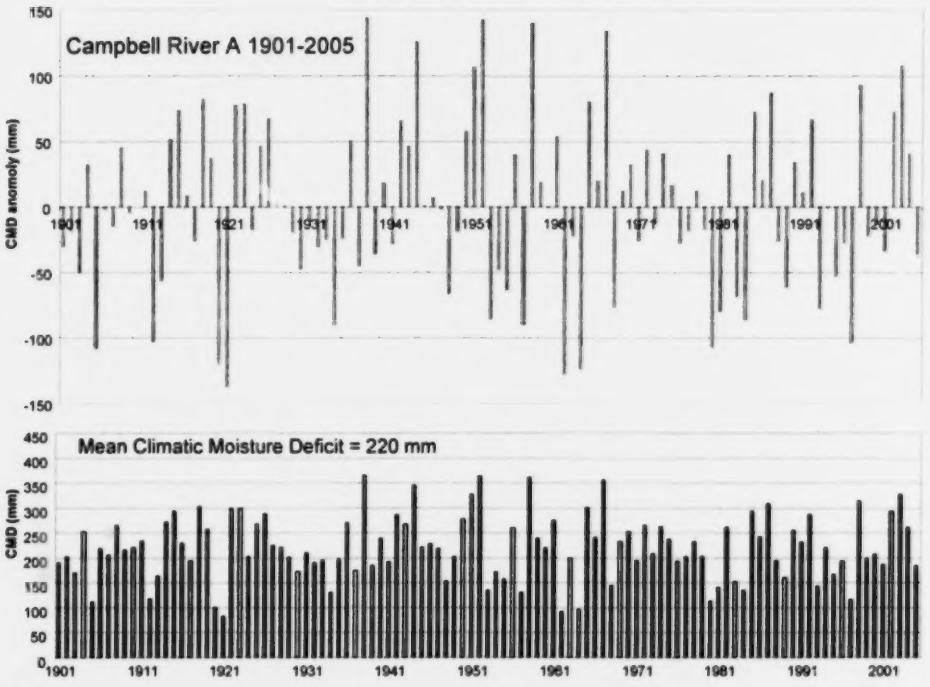


Figure 8. The lower panel shows the May-October climatic moisture deficit (CMD, mm) for Campbell River Airport for 1901 to 2005. The upper panel shows the inter-annual variation in CMD (CMD anomaly mm) obtained by subtracting the period mean CMD (220 mm) from the annual values. Negative values indicate that the CMD was lower (wetter season) than the average and positive ones higher (drier season) than average.

There can be a large inter-annual variability in the CMD, mainly as a result of the large inter-annual variation in summer rainfall. Data for 1901 to 2005 for the lowest elevation site illustrate this (Figure 8). The CMD varied from less than 100 to over 350 mm. In the upper panel, higher than average CMD years are indicated by positive value and lower than average by a negative value. A period with extremely high CMD occurred between the 1930s and 1960.

Occasionally there are two consecutive very dry years, e.g., 1951and 1952, 2002 and 2003. How this influences the vegetation will depend on the soil type and soil depth (Spittlehouse 2003). In 2003, anecdotal evidence indicates there was a large amount of die-back or "red flagging" of western redcedar on marginal sites (shallow soils).

The sites on the elevation transect are expected to show a similar inter-annual variation. Monthly precipitation for the 1901 to 2005 period for the higher elevation sites can be obtained by multiplying the monthly precipitation at Campbell River by the ratio of mean monthly precipitation for Campbell River to the other site for the current climate. Air temperature is adjusted by using the mean monthly lapse rates for the sites.

Regional variation in temperature and precipitation (Figures 6 and 7) influence the pattern of CMD on Vancouver Island. For example, the drier and warmer conditions in Victoria about 200 km southeast of Campbell River give a mean CMD of 312 mm. Unlike Campbell River, the 2002 and 2003 May to October periods for Victoria where much drier than the 1951 and 1952 periods.

Ecosystem climate: The 400 m grids of monthly temperature and precipitation for the 1961-90 normals were used to calculate similar fields of the other variables listed in Table 1. These data sets were then combined with ecosystem maps (BEC version 5) at the subzone variant level (Meidinger and Pojar 1991, BEC web site 2006). Climates of the units were obtained from the intersection of the 400-m grid points and the means, standard deviation and ranges for each unit were calculated. Table 3 presents a summary of selected variables by zones. The data for each variant are available at ftp://ftp.for.gov.bc.ca/HRE/external/!publish/Climate/.

Distinct differences between zones in temperature and precipitation can be seen in Table 3. The dry, warm low elevation southern interior zones contrast strongly with the cool wet coastal zones and cold, dry northern zones. The large variation in temperature and precipitation for some zones (Table 4) may be real or due to errors in ClimateBC interpolations or in mapping of the zones. However, the large variations occur in zones of large area and geographic range. The biggest variation is in the alpine zones (BAFA, CMA, IMA). These zones include areas of snow and ice that would extend the temperatures and precipitation ranges. The large climatic range in precipitation in the CWH reflects the differences between the east and west side of Vancouver Island and the north and south coasts. The range in temperature across this zone is similar to the range in others zones.

Applications of ClimateBC – Climate Change

Influence of climate change on snow accumulation and melt: High-elevation snowpacks are an important water source in the southern Okanagan. Future climate warming and changes in precipitation will affect the amount and timing of streamflow. In this example, ClimateBC's climate change scenarios are used to evaluate potential changes in snow accumulation and melt at the Upper Penticton Creek Watershed (Spittlehouse 2006). In this area, snowpacks persist from late October to late May or early June, depending on the year and elevation (Winkler *et al.* 2004).

Snow water equivalent (SWE) for the winter of 2000–2001 was simulated for a forested site at 1650 m using daily weather data and a snow accumulation and snow melt model (Spittlehouse and Winkler 2004). ClimateBC was used to determine the monthly changes in temperature and precipitation predicted for the 2050s and 2080s by the CGCM2-A2x scenario for this area. By the 2050s in the southern Okanagan, October to May mean temperatures are predicted to increase by 1.5–2.5°C, early winter precipitation to increase by 10%, and mid-winter

Table 3. 1969-90 climate normals for zones of the Biogeoclimatic classification system. Climate variable abbreviations are explained in Table 1.

&Zone	MAP	MSP	PAS	MAT	MTCM	MTWM	xTmin	FFP	DD<0	DD>5	SHM
	mm	mm	mm	°C	°C	°C	°C	days			
BAFA	1090	447	598	-2.6	-13.4	9.1	-44.6	15	2071	340	224
BG	342	161	100	6.1	-6.3	17.5	-35.8	118	575	1717	1145
BWBS	514	308	178	-0.3	-16.0	14.3	-46.5	77	2090	1023	480
CDF	1091	201	61	9.6	3.0	16.9	-15.4	204	31	1965	882
CMA	3198	816	1795	-0.3	-9.7	9.6	-40.0	43	1364	440	146
CWH	2893	651	427	6.7	-0.4	14.5	-22.1	151	191	1339	277
ESSF	1096	404	566	0.3	-10.6	11.5	-41.8	51	1413	650	305
ICH	920	342	379	3.3	-8.4	14.7	-38.9	88	922	1152	455
IDF	493	210	178	4.0	-7.7	15.1	-38.6	84	813	1238	743
IMA	1539	473	959	-2.0	-11.3	8.4	-43.1	20	1791	301	195
MH	3119	730	1198	2.8	-5.7	12.0	-33.2	76	690	781	195
MS	648	261	292	1.9	-9.3	12.8	-40.8	62	1101	848	512
PP	382	165	112	6.3	-5.9	17.9	-35.2	120	517	1762	1128
SBPS	473	228	191	1.7	-10.3	12.6	-43.2	35	1176	843	578
SBS	657	280	274	2.2	-10.3	13.6	-41.9	75	1169	988	196
SWB	691	352	322	-1.8	-13.9	10.9	-44.6	37	2038	525	125

&BAFA=Boreal Alti Fescue Alpine, BG=Bunch Grass, BWBS=Boreal Black and White Spruce, CDF=Coastal Douglas-fir, CMA= Coastal Mountain-heather Alpine, CWH=Coastal Western Hemlock, ESSF=Engelmann Spruce-Subalpine Fir, ICH=Interior Cedar Hemlock, IDF=Interior Douglas-fir, IMA=Interior Mountain-heather Alpine, MH=Mountain Hemlock, MS=Montane Spruce, PP=Ponderosa Pine, SBPS=Sub-boreal Pine Spruce, SBS=Sub-boreal Spruce, SWB=Spruce Willow Birch.

Table 4. One standard deviation on mean values of 1969-90 climate normals for zones of the Biogeoclimatic classification system presented in Table 3. Climate variable abbreviations are explained in Table 1. Zone names are explained below Table 3.

Zone	MAP	MSP	PAS	MAT	MTCM	MTWM	xTmin	FFP	DD<0	DD>5	SHM
	mm	mm	mm	°C	°C	°C	°C	days			
BAFA	524	150	345	1.2	1.6	1.2	1.5	19	330	114	69
BG	30	19	12	0.5	0.5	0.6	1.1	9	66	134	159
BWBS	61	37	24	0.7	2.1	0.7	1.4	8	259	107	69
CDF	166	47	13	0.3	0.5	0.4	1.3	19	14	87	180
CMA	1252	397	737	2.2	3.5	1.9	5.0	32	554	218	74
CWH	785	186	205	0.9	1.4	0.9	3.2	23	88	181	77
ESSF	251	76	156	0.8	0.9	0.8	1.2	15	176	116	63
ICH	197	59	111	1.0	1.0	1.0	1.7	14	162	175	90
IDF	82	27	39	0.7	0.7	0.9	1.3	13	101	160	113
IMA	351	113	251	1.2	1.2	1.4	1.6	20	278	133	58
MH	888	234	446	1.3	2.0	1.3	3.8	28	254	192	74
MS	128	46	74	0.6	0.7	0.7	1.0	11	103	110	104
PP	43	17	19	0.7	0.6	0.8	1.3	10	78	161	149
SBPS	55	32	31	0.6	0.7	0.7	1.0	18	90	104	109
SBS	107	38	58	0.6	0.8	0.6	1.0	11	108	104	29
SWB	134	77	89	0.7	1.5	0.8	1.2	18	191	97	25

to early spring precipitation to decrease by 0–5%. By 2080s the temperature may increase by 3 to 6°C and precipitation by 0 to 10%. These changes were applied to the weather data (solar radiation, humidity, and wind speed were kept constant) and the SWE simulated for the new conditions (Figure 9).

The warmer conditions in early winter did not affect the development of the snowpack. The precipitation increase resulted in a slightly higher SWE by the end of the year. The main effect of the increased temperature was an earlier start to the snow melt. Spittlehouse and Winkler (2004) show that a few consecutive days in late winter with air temperatures above 0°C are enough to start melt. Under the current climate, the temperature in March was not sufficient to start snow melt; however, in the changed climate warming in March was sufficient to initiate melt and reduce snowpack SWE. Cooler air temperature in early April stopped melt and SWE increased in response to precipitation. The main melt season began a week earlier in the climate change scenario for 2050 and finished 11 days earlier. With the 2080s scenario (4°C warming) melt begins in early March and finishes about a month earlier than under current conditions. Peak snow melt rates (20 mm d^{-1}) were similar in all scenarios. These data are consistent with other analyses of climate change impacts on Pacific Northwest snowpacks (Mote *et al.* 2003).

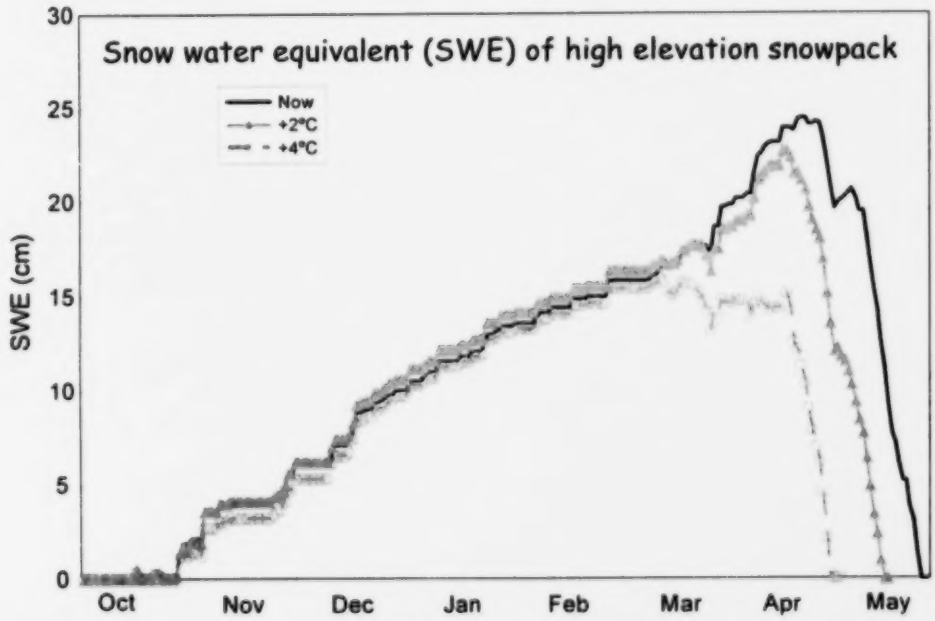


Figure 9. Snow water equivalent (cm) of the snowpack for a forested site at Upper Penticton Creek Watershed for the winter of 2000–2001 (solid line) and for climate change scenarios of 2°C warming (green triangles) (2050s climate) and 4°C warming (red circles and dashes) (2080s climate) in winter. (Adapted from Spittlehouse 2006.)

The results produced by ClimateBC in this scenario are important to consider. For example, an earlier end to the melt season could influence summer water resources through lower stream flow and greater soil moisture deficits. Global climate models suggest a 2–6°C warming in

the summer and a 5–40% decrease in summer precipitation, which would exacerbate the effects of earlier snow melt under a warming winter climate (Spittlehouse 2006). Note that a complete climate change sensitivity analysis requires evaluating the influence of a range of climate change scenarios and weather conditions. For example, the November to May precipitation at Upper Penticton Creek varied from 260 to 390 mm in the last decade. The date of disappearance of the snow pack varied from the beginning of May to early June (Spittlehouse and Winkler unpublished data). Under climate change this could mean that by the end of the century the snow pack could be gone by the end of March in some years.

Ecosystem climate distribution and climate change: Two approaches were used to evaluate how climate change might affect forest ecosystems. In one approach canonical discriminant functions, which are composite variables that account for climate differences among ecosystems, were developed. Canonical analysis was applied to the means of the annual variables to develop functions to discriminate between units (Hamann and Wang 2006). CAN1 in Figure 10 represents a gradient from more continental (positive values) to more maritime ecosystems (negative). CAN2 represents a gradient from cold and wet (positive) to warm and dry (negative) ecosystems. The location of the units in space is consistent with their nomenclature.

Figure 10. Location of BEC subzone variant climates in multivariate climate space. CAN1 represents a gradient from more continental (positive values) to more maritime ecosystems (negative). CAN2 represents a gradient from cold and wet (positive) to warm and dry (negative ecosystems. A2 (diamonds) and B2 (circles) refer to two climate change scenarios and the lines show the location and direction of the shift in climate space for the 2020s, 2050s and 2080s. The triangle indicates the difference between 1961-90 to 1998-2000 average conditions (From Hamann and Wang 2006).

The climates of the units were then re-mapped under various climate change scenarios. The arrows in Figure 10 indicate how the multivariate climate space of a BEC unit would shift relative to the current climate of the variants. This neglects that climate change is not uniform throughout BC and each ecosystem might be affected slightly differently. The main feature is a general shift towards warmer and drier conditions. Under a mid-range climate change scenario, by 2080 the warm dry climates of the Interior Douglas-fir (IDF) may occur in northeastern BC, areas currently experiencing Boreal White and Black Spruce (BWBS) climates (Table 3).

Climate change and selected ecosystems: Canonical analysis was used to determine how ecosystem climates might vary in space. Another approach to evaluate climate change impacts is to determine how the climate varies in time at a location. Ecosystem maps were overlain on grid-based climate data from ClimateBC to obtain descriptions of the climate of these units for current climate and then repeated for grid data adjusted for the climate change scenarios described earlier.

Table 5. The current (1961–1990 normals) and possible future climate (Canadian global climate model CGCM2-A2x scenario) of two biogeoclimatic ecosystem units for the 2050s. Unit means and one standard deviation (± SD) of each variable are presented. (From Spittlehouse 2006)

	Very Dry Maritime Coastal Western Hemlock (CWHxm2)			**Wet Cool Sub-Boreal Spruce (SBSwk1)**		
Area (ha)	580,250			785,950		
	1961–90	2050s	± SD	1961–90	2050s	± SD
Mean annual temperature (°C)	8.3	10.3	0.7	2.5	4.9	0.5
Mean July monthly maximum temperature (°C)	21.3	23.4	1	20.7	23.0	1
Mean January monthly minimum temperature (°C)	–1.0	0.8	1	–14.8	–10.0	1
Frost-free period (days)	173	223	22	78	116	10
May to September precipitation (mm)	370	350	120	350	380	40
October to April precipitation (mm)	1870	2020	590	488	510	90
Water equivalent of the annual snowfall (mm)	190	100	90	340	280	70
Summer heat/moisture index	48	58	15	41	47	5

Table 5 presents selected variables for two units under a present and a change scenario (CGCM2-A2x). The two units are the very dry maritime Coastal Western Hemlock unit (CWHxm2) on the eastern slope of Vancouver Island mountains and the wet cool Sub-Boreal Spruce unit (SBSwk1) in the Central Interior of BC on the west side of the Quesnel Highlands and on the MacGregor Plateau (Spittlehouse 2006). Conditions vary within a unit for any one variable, with precipitation showing the greatest range. The climate change scenario shifts all values of a variable in a unit by about the same amount so the standard deviation on the means stays the same. Both units are warmer by about 2°C and wetter in the winter. The CWHmx2 has less rain in the summer while there is a slight increase in summer rainfall for the SBSwk1. The

CWHxm2 climate changes towards that of the coastal plain on the east coast of the island. The implications for tree growth are that Douglas-fir should continue to grow well but western redcedar could disappear from currently marginal sites. The SBSwk1 climate is moving towards that of some units of the Interior Cedar–Hemlock zone. Warming of this unit may favour the growth of interior Douglas-fir and lodgepole pine over spruce. Other examples can be found in Appendix III.

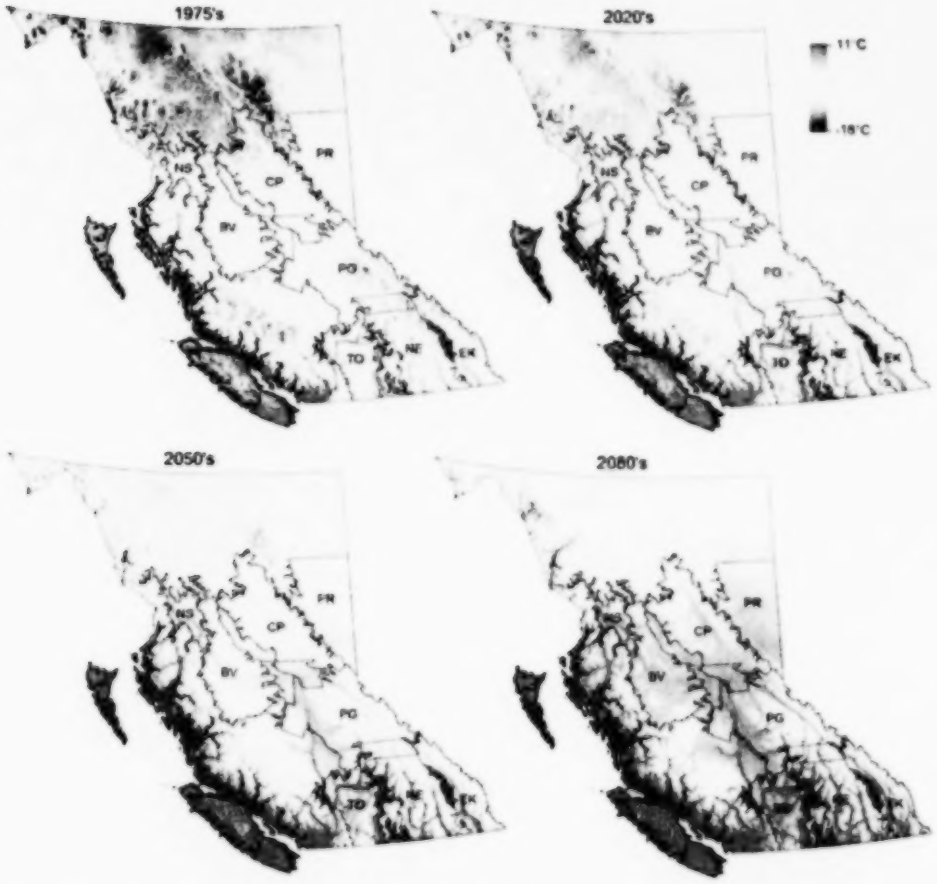


Figure 11. Maps of current lodgepole pine Seed Planning Zones overlaid on mean annual temperature for 1961-90 and predicted for 2020s, 2050s and 2080s. (From Wang *et al.* 2006a)

Seed planning zones and climate change: Seed planning zones are regions of relatively homogenous climate conditions where forest tree planting stock is deployed for reforestation. Planting stock is matched to planting conditions to avoid maladaptation and ensure optimal productivity. In this example the average MAT of different seed planning zones was determined before and after climate change (Wang *et al.* 2006a). Mean annual temperature for the 1961-90 reference period was from the 400 m grid described earlier. Mean annual temperature was then

determined for the CGCM2-A2x scenario for the 2020s, 2050s and 2080s. Lodgepole pine is planted within two elevation bands within each of these geographic areas. For simplicity, they were averaged in this example and small overlap zones were omitted.

Maps of lodgepole pine seed planning zones overlaid to mean annual temperatures (MAT) predicted by the program ClimateBC for current and future years are shown in Figure 11. Changes in MAT from current to the future years are substantial. The seed planning zone Bulkley Valley (BV) in the northwest interior plateau, for example, currently has a MAT of 1.6°C. However, it is predicted to have a MAT of 2.9°C in 2020s, which is about the same as current MAT in Nelson Okanagan (NE, 2.8°C) in the southeast interior plateau. In 2050's, Bulkley Valley is predicted to have a MAT of 4.1°C, which is higher than the current MATs of all seed planning zones. MAT has been found to be one of the most important climate variables driving the adaptation and productivity of lodgepole pine (Rehfeldt *et al.* 1999; Rehfeldt *et al.* 2004). This would imply that the impact on the species and reforestation practices might be drastic if climate changes as predicted. These high-resolution climate variable coverages could be used to redefine and revise current seed zones based on a multivariate characterization of the climate envelop of each, and identify suitable future planting environments for seed originating from different locations (Wang *et al.* 2006a).

Management Implications

The ClimateBC data provide a baseline to assess the effect of current and future climate on ecosystems and species in BC. They have been used in production of the MoFR Climate Change Task Team Report. The data will be critical in determining climate envelopes for species and provenances to aid species selection and development of seed transfer guidelines. The program also provides opportunities to improve our knowledge of hydrologic regimes in BC.

Care needs to be taken when applying ClimateBC. Its output should be viewed as reference values. These scale-free data represent open areas (weather stations) at 1.5-m height. Thus care needs to be taken when using them in resource analysis. The microclimate of small-scale topographic features, e.g., frost pockets, rivers and lakes, will not be accurately represented. Temperatures in forest canopies are often a few degrees cooler during the day and warmer at night than in open areas. Air temperature under a snow pack can be substantially warmer than the air above the pack. Consequently, as with using individual weather station data, users need to know how the environment of the organism or small-scale geographic feature of interest may vary from the reference values generated from the scale-free data.

Projected changes in climate over the next 100 years are large. Many BEC units will see a change in climate outside of the range in which they presently exist. Consequently, there will be significant impact on forest species. In some situations there could initially be benefits such as increased productivity due to the warming of high elevation and northern ecosystems. However, other species will find themselves in non-optimal environments.

The many users of forest resources have a range of vulnerabilities to climate change and priorities for responding to impacts. There are numerous challenges to adaptation in forestry, not the least of which is the uncertainty in the magnitude and timing of future climate change and the response of forest species. Furthermore, current forest utilization and preservation is based on how forests developed under past climatic conditions. Spittlehouse (2005) has summarized the many challenges facing adaptation to climate change in forest management.

Numerous adaptive actions have been proposed for forest management (Spittlehouse and Stewart (2003). They can be grouped into three categories: societal adaptation (e.g., forest policy

to encourage adaptation, revision of conservation objectives, changes in expectations), adaptation of the forest (e.g., species selection, tree breeding, stand management, fire smart landscapes), and adaptation to the forest (e.g., change rotation age, use more salvage wood, modify wood processing technology). Many of these forest management activities already implicitly consider climate. The challenge is to develop explicit descriptors of system responses to climate that can be used for management. An important step in this direction was the production of the high-resolution spatial climate data for current and future climate change scenarios for BC (Wang *et al.* 2006a) described in this report. The challenge now is to link these data with ecosystem and species information to determine impacts of climate change and develop adaptive responses (Spittlehouse and Stewart 2003, Spittlehouse 2005, Hamann and Wang 2006, Wang *et al.* 2006b).

How and when does the forest community begin the process of adapting to climate change? Asking the questions about how to adapt will help determine: research and educational needs, vulnerability of forest resources, policies to facilitate implementation of adaptation in forest management, and monitoring systems to identify problems induced by climate change. Including adaptation to climate change as part of forest planning does not necessarily require a large financial investment now with an unknown future payback time (Spittlehouse 2005, Spittlehouse and Stewart 2003).

Extension

Presentations: Numerous presentations have been made to professional and public groups on climate change about this project or have used information provided by ClimateBC (see Appendix II). Presentations about ClimateBC's development and validation were made at two scientific meetings:

Hamann, A., D.L. Spittlehouse, T. Wang and S.N. Aitkin. 2005. Impacts of climate change on forest ecosystems in British Columbia and adaptation strategies for forest management, Adapting to Climate Change in Canada 2005: Understanding Risks and Building Capacity, 4-7 May 2005, Natural Resources Canada, Montreal, QC. http://www.adaptation2005.ca/abstracts/hamann_e.html

Wang, T., D.L. Spittlehouse and A. Hamann. 2005. Development of high spatial resolution climate data for British Columbia, 30 May- 4 June 2005, 39th Congress of the Canadian Meteorological and Oceanographic Society, Vancouver, BC.

Data access: The ClimateBC program and associated data files and a web-based version are available at http://genetics.forestry.ubc.ca/cfgc/climate-models.html.

Grid-based data for the monthly temperature and precipitation at 400 m spacing are available at: ftp://ftp.for.gov.bc.ca/HRE/external/!publish/Climate/. Instruction for determining derived variables (Appendix 1) and climate change scenarios are also on the site.

Climates of the variant unit of the MoFR ecosystem classification were obtained from the intersection of the 400-m grid points with ecosystem maps. The means, standard deviation and ranges for each variant are available at ftp://ftp.for.gov.bc.ca/HRE/external/!publish/Climate/. The data are also available for two climate change scenarios for 2050.

Publications: Publications on development and testing of ClimateBC, applying ClimateBC in vegetation, genecology and hydrology studies, and implications of climate change in forest management:

Hamann A. and T.L. Wang. 2004. Models of climatic normals for genecology and climate change studies in British Columbia. *Agricultural and Forest Meteorology* 128:211-221.

Hamman A. and T.L. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology* (accepted).

Spittlehouse, D.L. 2005. Integrating climate change adaptation into forest management. *The Forestry Chronicle* 81:691–695.

Spittlehouse, D.L. 2005. Climate change impacts and adaptation in forestry. In: Climate Change and Forest Genetics, Proc.29th Meeting, Canadian Tree Improvement Assoc., part 2, Symposium, G.A. O'Neill and J.D. Simpson (eds) pp. 43-48.

Spittlehouse, D.L. 2006. ClimateBC: Your access to interpolated climate data for BC. *Streamline Watershed Management Bulletin* 9:16-21.

Wang, T., A. Hamann, D.L. Spittlehouse and S.N. Aitken. 2006a. Development of scale-free climate data for western Canada for use in resource management. *International Journal of Climatology* 26:383–397.

Wang, T., A. Hamann, A. Yanchuk, G.A. O'Neill, and S.N. Aitken. 2006b. Use of response functions in selecting lodgepole pine populations for future climate. *Global Change Biology* (accepted).

Woods, A., K.D. Coates and A. Hamann. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate change? *Bioscience* 55: 761-769

Others papers are under review by journals.

Promotion: An article was published in Streamline Watershed Management Bulletin describing ClimateBC, applications and how to access the program (Spittlehouse 2006). Short articles were also published in newsletters of the BC Institute of Agrologists (March 2006 issue) and the College of Applied Biology (March 2006 issue). An article is planned for the September/October issue of the professional forester newsletter and one for the summer issue of a geoscientist newsletter.

Applications of ClimateBC:

BC Ministry of Forests and Range Climate Change Task Team: Figures in report, development of options for responding to climate change.

Green, S. (University of Northern BC): Climate and tree growth.

Guthrie, R. (MoE): Using precipitation to improve Vancouver Island terrain stability maps.

Moore, D. (UBC): Hydrologic studies in BC.

O'Neill, G. (MoFR), Hamann, A., (U. Alberta), Wang, T. (UBC): Predicting lodgepole pine productivity impacts due to genetic maladaptation associated with projected climate change.

O'Neill, G. (MoFR): Climate based seed planning zones.

Parker, W. (Lakehead Univ.): Climate and growth response of coastal Douglas-fir provenance data and impact of climate change on growth and seed transfer.

Shen, S. (University of Alberta), Bernhard, L. (Alberta Sustainable Resource Development), Niemi, F. (Daishowa-Marubeni Corporation): Climate and tree genetics.

Spittlehouse, D.L. (MoFR): Temperature and precipitation maps of BC for the BC Assessment of Climate Change.

Spittlehouse, D.L. (MoFR): Temperature and precipitation maps of BC, climate descriptions, CMD and E_{ref} of BEC units for the BC Hydrologic Compendium.

Stevens, T. (MoE): Influence of climate change on BC parks.

Waterhouse, L (MoFR): Mapping affect of climate change on spotted owl habitat.

User support: Promotion of ClimateBC has resulted in a number of enquiries about its use by biologists, ecologists, geneticists and geoscientists. The project team has spent many hours explaining ClimateBC and helping users use its output.

Literature Cited

Allen R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and Drainage paper FAO56, U.N. Food and Agriculture Organization, Rome. www.fao.org/docrep/x0490E (Last accessed Nov 2005).

BEC web site. 2006. http://www.for.gov.bc.ca/hre/becweb/resources/maps/versions.html. (Last accessed May 2006.)

Bristow, K.L. and G.S. Campbell. 1984. On the relationship between incoming solar radiation and daily maximum and minimum air temperature. *Agric. For. Meteorol.* 31:159-166.

Canadian Climate Scenarios Project. 2005. www.ccsn.ca (Last accessed March 2006.)

Daly, C. R.P. Neilson and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *J. Applied Meteorology* 33:140-158.

Daly, C., G. Taylor, and W. Gibson. 1997. The PRISM Approach to Mapping Precipitation and Temperature. *In*: 10th. Conf. on Applied Climatology, Reno, NV, Amer. Meteor. Soc., 10-12.

Daly C., W.P. Gibson, G.H. Taylor, G.L. Johnson and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. *Climate Research* 22:99-113.

Flato G.M., G.J. Boer, W.G. Lee, N.A. McFarlane, D. Ramsden D, M.C. Reader and A.J. Weaver. 2000. The Canadian Centre for Climate Modelling and Analysis global coupled model and its climate. *Climate Dynamics* 16:451-467.

Hamann A, and T.L. Wang. 2004. Models of climatic normals for genecology and climate change studies in British Columbia. *Agricultural and Forest Meteorology* 128:211-221.

Hamman A. and T.L. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology* (accepted).

Hamann, A., D.L. Spittlehouse, T. Wang and S.N. Aitkin. 2005. Impacts of climate change on forest ecosystems in British Columbia and adaptation strategies for forest management, Adapting to Climate Change in Canada 2005: Understanding Risks and Building Capacity, 4-7 May 2005, Natural Resources Canada, Montreal. http://www.adaptation2005.ca/abstracts/hamann_e.html (Last accessed 8 May 2006).

Hay, J.E., 1979. Calculation of monthly mean solar radiation for horizontal and inclined surfaces. *Solar Energy* 23:301-307.

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu, (eds.). 2001. Climate change 2001: the scientific basis. Intergovernmental Panel on Climate Change, Cambridge Univ. Press, New York, NY.

Johns T.C. and 11 others. 2003. Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios. *Climate Dynamics* 20:583-612.

Mather, J.R. and R.A. Ambrosiak. 1986. A search for understanding potential evapotranspiration. *The Geographical Review* 76:355-370.

Meidinger, D.V., and J. Pojar (compliers and editors). 1991. Ecosystems of British Columbia. Special Report Series Publ. No. 6, Min. Forests, Victoria, B.C.

Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International J. Climatology* 25:693-712.

Mote, P.W., E.A. Parson, A.F. Hamlet, K.N. Ideker, W.S. Keeton, D.P. Lettenmaier, N.J. Mantua, E.L. Miles, D.W. Peterson, D.L. Peterson, R. Slaughter, and A.K. Snover. 2003. Preparing for climate change: The water, salmon and forests of the Pacific Northwest. *Climatic Change* 61:45–88.

Ouranos. 2006. www.ouranos/doc/produit2_e.html. (Last accessed 8 May 2006).

Rehfeldt, G.E., C.C. Ying, D.L. Spittlehouse and D.A. Hamilton. 1999. Genetic responses to climate in *Pinus contorta*: niche breadth, climate change and reforestation. *Ecological Monographs* 69:375-407.

Rehfeldt G.E., N.M.Tchebakova, and E.I. Parfenova. 2004. Genetic responses to climate and climate-change in conifers of the temperate and boreal forests. *Recent Research and Development in Genetics and Breeding* 1:113-130.

Running, S.W., R.R. Nemani and R.D. Hungerford. 1987. Extrapolation of synoptic meteorological data in mountainous terrain and its use for simulating forest evaporation and photosynthesis. *Canadian J. Forest Research* 17:472-483.

Spittlehouse, D.L. 2003. Water availability, climate change and the growth of Douglas-fir in the Georgia Basin. *Canadian Water Resources J.* 28:1-6.

Spittlehouse, D.L. 2004. The climate and long-term water balance of Fluxnet Canada's coastal Douglas-fir forest. Proc. 26th Conference on Agricultural and Forest Meteorology, 23-26 August 2004, Vancouver, BC, American Meteorological Society, Boston, MA, P1.42, 6 pp.

Spittlehouse, D.L. 2005. Integrating climate change adaptation into forest management. *The Forestry Chronicle* 81:691–695.

Spittlehouse, D.L. 2005. Climate change impacts and adaptation in forestry. In: Climate Change and Forest Genetics, Proc.29th Meeting, Canadian Tree Improvement Assoc., part 2, Symposium, G.A. O'Neill and J.D. Simpson (eds) pp. 43-48.

Spittlehouse, D.L. 2006. ClimateBC: Your access to interpolated climate data for BC. *Streamline Watershed Management Bulletin* 9:16-21.

Spittlehouse, D.L. and R.B. Stewart. 2003. Adapting to climate change in forest management. http://www.forrex.org/jem/2003/vol4/no1/art1.pdf. Printed version, *J. Ecosystems and Management* (2004) 4(1):7-17.

Spittlehouse, D.L. and R.D. Winkler. 2004. Snowmelt in a forest and clearcut. *In*: Proceedings of the 72nd Western Snow Conference, Richmond, BC, pp.33-43.

Standing Senate Committee on Agriculture and Forestry. 2003. Climate change: we are at risk. Final Report, Gov. Canada, Ottawa, ON.

Thornthwaite, C.W. 1948. Towards a rational approach to classification of climate. *Geographical Review* 38:55-94.

Tuhkanen, S. 1980. Climatic parameters and indices in plant geography. *Acta Phytogeographica Suecica* 67:1-105.

Wang, T., A. Hamann, D.L. Spittlehouse and S.N. Aitken. 2006a. Development of scale-free climate data for western Canada for use in resource management. *International Journal of Climatology* 26:383–397.

Wang, T., A. Hamann, A. Yanchuk, G.A. O'Neill, and S.N. Aitken. 2006b. Use of response functions in selecting lodgepole pine populations for future climate. *Global Change Biology* (accepted).

Winkler, R., D. Spittlehouse, T. Giles, B. Heise, G. Hope, and M. Schnorbus. 2004. Upper Penticton Creek: How forest harvesting affects water quantity and quality. *Streamline Watershed Bulletin* 8:18–20.

WMO. 1989. Calculation of Monthly and Annual 30-Year Standard Normals, WCDP-No. 10, WMOTD/No. 341. World Meteorological Organization, Geneva.

Woods, A., K.D. Coates and A. Hamann. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate change? *Bioscience* 55: 761-769

Appendix I: Equations for Calculating Derived Variables

The equation numbers are those presented in Wang *et al.* (2006a). These equations can be applied to the 400 km temperature and precipitation grids to create derived variables. For climate change studies, the changes are applied to the monthly temperature and precipitation data and the variables recalculated.

1. Degree-days (DD)

Formulae [4 to 6]:

$$DD_{est} = \sum_{1}^{12} (T_m - base) \times N_m \quad \text{for } T_m > base \quad [4]$$

$$DD_{est} = \sum_{1}^{12} (base - T_m) \times N_m \quad \text{for } T_m < base \quad [5]$$

$$DD = a + b\, DD_{est} \quad [6]$$

Where base is base temperature (0, 5 or 18 °C), T_m is the monthly temperature and N_m is the number of days in the month.

Degree days <0°C:

DD = 137.09 + 0.97985 DD_{est} for Tave01 or Tave02 <0
Else: DD = 87.70 - 19.25*Tave01 for Tave01 > 0
IF DD<0, DD=0

Tave01 and Tave02 are the average January and February temperatures respectively (°C)

Degree days >5°C:

DD_{ob} = 75 + 1.0*DD_{est} (adjustment from evaluation with weather station data)
DD = DD_{ob}*1.0679 - 36.5 (further adjusted for PRISM data inaccuracies)

Degree days <18°C:

DD = 0.988*DD_{est} - 115

Degree days > 18°C: Formula [7]

$$DD_i = a/ (1+ e^{-(Ti-T0)/b})$$

Ti = Tave07 * 1.131 - 1.766
a = 505.8: b = 1.7953: T0 = 20.9611
Tave07 = July average temperature (°C)

DD = DD_i*1.119 - 3.57

2. The day of the year on which accumulated growing degree-days (DD>5°C) reach 100 ($DD5_{100}$): Formula [8]

$$DD5_{100} = ED_{below} + (ED_{above} - ED_{below}) \times (100 - DD5_{below}) / (DD5_{above} - DD5_{below})$$

where DD_{below} and DD_{above} are the days of the year at the ends of the months, on which the accumulated DD>5°C are just below and above 100 respectively; $DD5_{below}$ and $DD5_{above}$ are accumulated DD>5°C at the ends of the months when the accumulated DD>5°C are just below and above 100 respectively

Visual basic code:

```
dd5c = 0
```

```
If Tave(1) > 5 Then dd5c = dd5c + (Tave(1) - 5) * 31: dd5c01 = dd5c + 7 Else dd5c01 = dd5c + 7
If Tave(2) > 5 Then dd5c = dd5c + (Tave(2) - 5) * 28: dd5c02 = dd5c + 14 Else dd5c02 = dd5c + 14
If Tave(3) > 5 Then dd5c = dd5c + (Tave(3) - 5) * 31: dd5c03 = dd5c + 21 Else dd5c03 = dd5c + 21
If Tave(4) > 5 Then dd5c = dd5c + (Tave(4) - 5) * 30: dd5c04 = dd5c + 28 Else dd5c04 = dd5c + 28
If Tave(5) > 5 Then dd5c = dd5c + (Tave(5) - 5) * 31: dd5c05 = dd5c + 35 Else dd5c05 = dd5c + 35
If Tave(6) > 5 Then dd5c = dd5c + (Tave(6) - 5) * 30: dd5c06 = dd5c + 42 Else dd5c06 = dd5c + 42
If Tave(7) > 5 Then dd5c = dd5c + (Tave(7) - 5) * 31: dd5c07 = dd5c + 49 Else dd5c07 = dd5c + 49
If Tave(8) > 5 Then dd5c = dd5c + (Tave(8) - 5) * 31: dd5c08 = dd5c + 56 Else dd5c08 = dd5c + 56
If Tave(9) > 5 Then dd5c = dd5c + (Tave(9) - 5) * 30: dd5c09 = dd5c + 63 Else dd5c09 = dd5c + 63
If Tave(10) > 5 Then dd5c = dd5c + (Tave(10) - 5) * 31: dd5c10 = dd5c + 70 Else dd5c10 = dd5c + 70
If Tave(11) > 5 Then dd5c = dd5c + (Tave(11) - 5) * 30: dd5c11 = dd5c + 77 Else dd5c11 = dd5c + 77
If Tave(12) > 5 Then dd5c = dd5c + (Tave(12) - 5) * 31: dd5_p = dd5c + 84 Else dd5_p = dd5c + 84
heat_sum = 100
date_below = 15
date_above = 46
sum_below = dd5c01
sum_above = dd5c02
If dd5c02 < heat_sum Then date_below = 60: date_above = 91: sum_below = dd5c02: sum_above = dd5c03
If dd5c03 < heat_sum Then date_below = 91: date_above = 121: sum_below = dd5c03: sum_above = dd5c04
If dd5c04 < heat_sum Then date_below = 121: date_above = 152: sum_below = dd5c04: sum_above = dd5c05
If dd5c05 < heat_sum Then date_below = 152: date_above = 182: sum_below = dd5c05: sum_above = dd5c06
If dd5c06 < heat_sum Then date_below = 182: date_above = 213: sum_below = dd5c06: sum_above = dd5c07
If dd5c07 < heat_sum Then date_below = 213: date_above = 244: sum_below = dd5c07: sum_above = dd5c08
If dd5c08 < heat_sum Then date_below = 244: date_above = 274: sum_below = dd5c08: sum_above = dd5c09
If dd5c09 < heat_sum Then date_below = 274: date_above = 305: sum_below = dd5c09: sum_above = dd5c10
If sum_above > 100 Then
   dd5_100 = date_below + (date_above - date_below) * ((heat_sum - sum_below) / (sum_above - sum_below))
  dd5_100 = 1.1225 * dd5_100 - 20.68
  dd5_100 = Round(dd5_100, 0)
  Else: dd5_100 = "."
End If
```

3. Number of Frost-Free Days (NFFD); Formula [9]

$$P_i = 1/(1 + a*e^{-(Ti*b)})$$

Where P_i is the proportion of monthly NFFD, T_i is the monthly minimum temperature, a=1.15 and b=0.40

$NFFD_{est} = \Sigma(P_i*N_i)$

where N_i is the number of days for each month

$NFFD_{e2} = 1.0753 * NFFD_{est} - 6.18$ (adjustment from evaluation with weather station data)

$NFFD = NFFD_{e2} * 0.9784 + 6.6$ (further adjusted for PRISM data inaccuracies)

4. Frost-Free Period (FFP), Beginning of Frost-Free Period (bFFP) and end of Frost-Free Period (eFFP): Formulae [10-11]

$$bFFP = MD_{below} + (MD_{above} - MD_{below}) \times (T0 - T_{below}) / (T_{above} - T_{below}) \quad [10]$$

$$eFFP = MD_{above} + (MD_{below} - MD_{above}) \times (T_{above} - T_0) / (T_{above} - T_{below}) \quad [11]$$

Where MD_{below} and MD_{above} are the days of the year for the mid-date of the months when the mean monthly temperatures are just below (T_{below}) and above (T_{above}) the threshold T_0 respectively.

FFP = eFFP – bFFP

Visual basic code:

```
'FFP

fall_frost = 3.5 + TD / 45
spring_frost = 3.1 +TD / 45
'fall_frost = 3.7
'spring_frost = 3.7

If Tmin(1) > spring_frost Then bffp = 0: effp = 365: ffp = 365: GoTo Skip_ffp
k = 0
For i = 1 To 7 'from jan-aug
   If Tmin(i) < spring_frost And Tmin(i + 1) > spring_frost Then
  k = i
  If k = 1 Then spring_date_below = 15: spring_date_above = 46: spring_temp_below = Tmin(1):
    spring_temp_above = Tmin(2)
  If k = 2 Then spring_date_below = 46: spring_date_above = 75: spring_temp_below = Tmin(2):
    spring_temp_above = Tmin(3)
  If k = 3 Then spring_date_below = 75: spring_date_above = 106: spring_temp_below = Tmin(3):
    spring_temp_above = Tmin(4)
  If k = 4 Then spring_date_below = 106: spring_date_above = 136: spring_temp_below = Tmin(4):
    spring_temp_above = Tmin(5)
  If k = 5 Then spring_date_below = 136: spring_date_above = 167: spring_temp_below = Tmin(5):
    spring_temp_above = Tmin(6)
  If k = 6 Then spring_date_below = 167: spring_date_above = 198: spring_temp_below = Tmin(6):
    spring_temp_above = Tmin(7)
  If k = 7 Then spring_date_below = 198: spring_date_above = 228: spring_temp_below = Tmin(7):
    spring_temp_above = Tmin(8)
  End If
  Next i
  If k = 0 Then bffp = ".": effp = ".": ffp = 0: GoTo Skip_ffp
  bffp = spring_date_below + (spring_date_above - spring_date_below) * ((spring_frost -
     spring_temp_below) / (spring_temp_above - spring_temp_below))
  bffp = Round(bffp, 0)
 k1 = 0
   For i = 7 To 12 'jul to jan
    If Tmin(i) > fall_frost And Tmin(i + 1) < fall_frost Then
      k1 = i
      If k1 = 7 Then fall_date_above = 198: fall_date_below = 228:
        fall_temp_above = Tmin(7): fall_temp_below = Tmin(8)
      If k1 = 8 Then fall_date_above = 228: fall_date_below = 259:
        fall_temp_above = Tmin(8): fall_temp_below = Tmin(9)
      If k1 = 9 Then fall_date_above = 259: fall_date_below = 289:
        fall_temp_above = Tmin(9): fall_temp_below = Tmin(10)
      If k1 = 10 Then fall_date_above = 289: fall_date_below = 320:
        fall_temp_above = Tmin(10): fall_temp_below = Tmin(11)
      If k1 = 11 Then fall_date_above = 320: fall_date_below = 350:
        fall_temp_above = Tmin(11): fall_temp_below = Tmin(12)
      If k1 = 12 Then fall_date_above = 350: fall_date_below = 381: fall_temp_above = Tmin(12):
        fall_temp_below = Tmin(1)
   End If
   Next i
   If k1 = 0 Then effp = bffp: ffp = 0: GoTo Skip_ffp
   effp = fall_date_above + (fall_date_below - fall_date_above) * ((fall_temp_above -fall_frost) /
     (fall_temp_above - fall_temp_below))
```

```
    t = 1
    bffp = 1.03 * bffp
    effp = 1.05 * effp - 22
    bffp = Round(bffp, 0)
    effp = Round(effp, 0)
    If bffp > 202 Then bffp = 202
    If effp < 190 Then effp = 190
    ffp = effp - bffp
    If ffp < 0 Then ffp = 0: effp = bffp
    If ffp > 365 Then ffp = 365: bffp = 0: effp = 365
Skip_ffp:
```

5. Extreme Minimum Temperature (EMT): Formula [12]

$$EMT = y_0 + a/(1 + e^{-(T-x0)/b})$$

Where y_0=-51.074, $x0$=3.3162 and b=6.8627,
T = mean minimum temperature of the coldest month (°C)

6. Precipitation as Snow (PAS): Formula [13]

$$P_i = 1/(1 + e^{-(Ti-x0)/b})$$

where P_i is the proportion of the precipitation falling as snow (water equivalent) for month *i* and T_i is the monthly mean temperature (°C)

Month (i)	*x0*	*b*
1	-2.9901	-2.50353
2	-1.3948	-2.0004
3	0.5473	-1.5719
4	2.0928	-1.6527
5	4.078	-1.7428
9	1.4927	-2.8948
10	0.8099	-1.6612
11	-1.5627	-2.4907
12	-2.5909	-2.2108

$PAS_{est} = \Sigma (P_i * PPT_i)$

PPT_i is the monthly precipitation, P_6, P_7 and $P_8 = 0$

$PAS_{e2} = 7.53 + 0.978 * PAS_{est}$ (adjustment from evaluation with weather station data)

$PAS = 12.8 + 0.9106 * PAS_{e2}$ (further adjusted for PRISM data inaccuracies)

Appendix II: Effect of climate change on selected ecosystems

Climate change in Thompson Very Dry Hot Ponderosa Pine Variant (PPxh2)

The most significant climate change with the A2x scenario for the 2020s is a warming of temperature. The following table compares the A2x scenario of the PPxh2 to the warmer, Bunch Grass (BG) biogeoclimatic variants (Meidinger and Pojar 1991) (BGxh1, BGxh2):

Variable	Significance of change to PPxh2
Day of year DD5 = 100	< BGxh2; < BGxh1
Frost free period	>> BGxh2; > BGxh1
T Minimum January	≈ BGxh1
T Maximum July	= BGxh1
Mean annual temperature	≈ BGxh1
Precipitation as snow	≈ BGxh2
Summer precip / moisture	≈ > BGxh2; ≈ > BGxh1
Other precipitation	No significant change

From the above table, it appears that the climate in the PPxh2 will approach that of the BGxh1 and definitely overlap with the BGxh2. Both of these are grassland zones with limited distribution and abundance of ponderosa pine, mostly on coarser-textured soils.

The precipitation within these three variants does not differ significantly. It is the difference temperature and its effect on evaporation and soil moisture, factors that determine the dominance of grasslands over forest. The main tree species in these three variants is Ponderosa pine. The temperature means and extremes should not limit the potential for the presence of Ponderosa pine. However, the soil moisture impacts will limit its range and abundance. Ponderosa pine does not generally form well-stocked, vigorous stands in the BG zone. Therefore, the impact to forestry will be a significant reduction in appropriate sites for growing trees of reasonable productivity and volume.

Climate change in Western Moist Maritime Mountain Hemlock Variant (MHmm1)

The most significant climate change with the A2x scenario for 2050s is a warming of temperature, although there is a slight increase in winter precipitation. The MHmm1 occurs in elevations above several Coastal Western Hemlock (CWH) variants, including CWHvm2, CWHwh2, and CWHmm2. The following table compares the A2x scenario of the MHmm1 to various CWH biogeoclimatic variants:

Variable	Significance of change to MHmm1
Day of year DD5 = 100	≈ CWHvm2
Frost free period	≈ CWHvm2
T Minimum January	≈ CWHvm2
T Maximum July	≈ CWHvm1
Mean annual temperature	≈ CWHvm2
Precipitation as snow	≈ CWHvm2
Summer precip / moisture	≈ CWHvm1 / CWHvm2
Other precipitation	No significant change in summer; slightly higher in winter.

From the above table, it appears that the future climate in the MHmm1 will approach that of the CWHvm2.

The main difference between the MHmm1 and the CWHvm2 is mountain hemlock replacing western hemlock, and a significant increase in western redcedar. The other major difference could be in productivity of the forests. Zonal ecosystems in the MH are generally of poor productivity, primarily due to snow, temperature and the resulting short growing season.

Other examples can be found on pages 20-21 of this report.

Appendix III: Presentations related to the project

Dr. Dave Spittlehouse, Research Branch, BC Min. Forests, Victoria

July 2004: "Climate change impacts and adaptation in forestry", Canadian Tree Improvement Association 29th Biannual Meeting and WFGA Conference, Climate Change and Forest Genetics, Kelowna.
Oct 2004: "Adaptation in forestry", Canadian Institute of Forestry and Society of American Foresters annual meeting, Edmonton.
Nov 2004: C-CAIRN Climate Change Workshop, Prince George.
Dec. 2004 ClimateBC, Climate change and BEC, Ecologist meeting, Victoria
Jan 2005: Coastal Silviculture Committee, Nanaimo.
March 2005: Lecture on hydrology and climate change to resource management class, UCC, Kamloops.
Feb. 2005: Briefing on climate change issues to chief forester and acting assistant chief forester, Victoria
April 2005: "Adaptation to Climate Change" Implications of Climate Change in BC's Southern Interior, Revelstoke
Nov. 2005: "Climate Change and BC's Forests" at Forests and Environmental Stress, Forest Biology Symposium, Univ. Victoria, Victoria
Dec. 2005: "Overview of predicted climate changes in BC" at The Future Forest Ecosystems of BC Exploring Opportunities, UNBC, Prince George
March 2006: Lecture on hydrology and climate change to resource management class, TRU, Kamloops.

Dr Andreas Hamann, Univ. Alberta, Edmonton, AB

June 2004: Species range mapping workshop, Min. Land Water and Air Protection, Victoria.
July 2004: Canadian Tree Improvement Association 29th Biannual Meeting, Climate Change and Forest Genetics, WFGA Conference, Kelowna.
October 2005: SER International Conference, Victoria.
Nov 2004: ITAC Meeting, Vernon.
Nov 2004: C-CAIRNBC Climate Change Workshop, Prince George.
Jan 2005: Coastal Silviculture Committee, Nanaimo.
March 2005: Extended presentation and discussion session for Forest Practices Board, Victoria.
April 2005: "Potential effects of climate change on ecosystem and tree species distribution in British Columbia", Implications of Climate Change in BC's Southern Interior, Revelstoke.
May 2005: Impacts of climate change on forest ecosystems in British Columbia and adaptation strategies for forest management, Adapting to Climate Change in Canada 2005: Understanding Risks and Building Capacity, Natural Resources Canada, Montreal

Tongli Wang, Centre for Forest Gene Conservation, UBC Vancouver

July 2004: "Climate models and genetic applications for lodgepole pine in British Columbia"' Canadian Tree Improvement Association 29th Biannual Meeting, Climate Change and Forest Genetics, Kelowna.
March 2006: "ClimateBC and its applications" (poster). 2006 Pacific Ecology & Evolution Conference Bamfield Marine Science Centre.
May-June 2005: "Development of high spatial resolution climate data for British Columbia", Canadian Meteorological and Oceanographic Society 39th Congress, Vancouver.

Dec. 2005: Invited talk to a discussion group on finding a fine scale climate surfaces for Okanagan agriculture, Penticton.
August 2005: "Selection of lodgepole pine populations for reforestation in changing climates", XXII IUFRO World Congress, Brisbane, Australia.

Dr Sally Aitkin, Centre for Forest Gene Conservation UBC Vancouver

March 2005: Interior Silviculture Committee meeting.
Dec. 2005: The Future Forest Ecosystems of BC Exploring Opportunities, UNBC, Prince George.